Magnetic Field Feasibility Study


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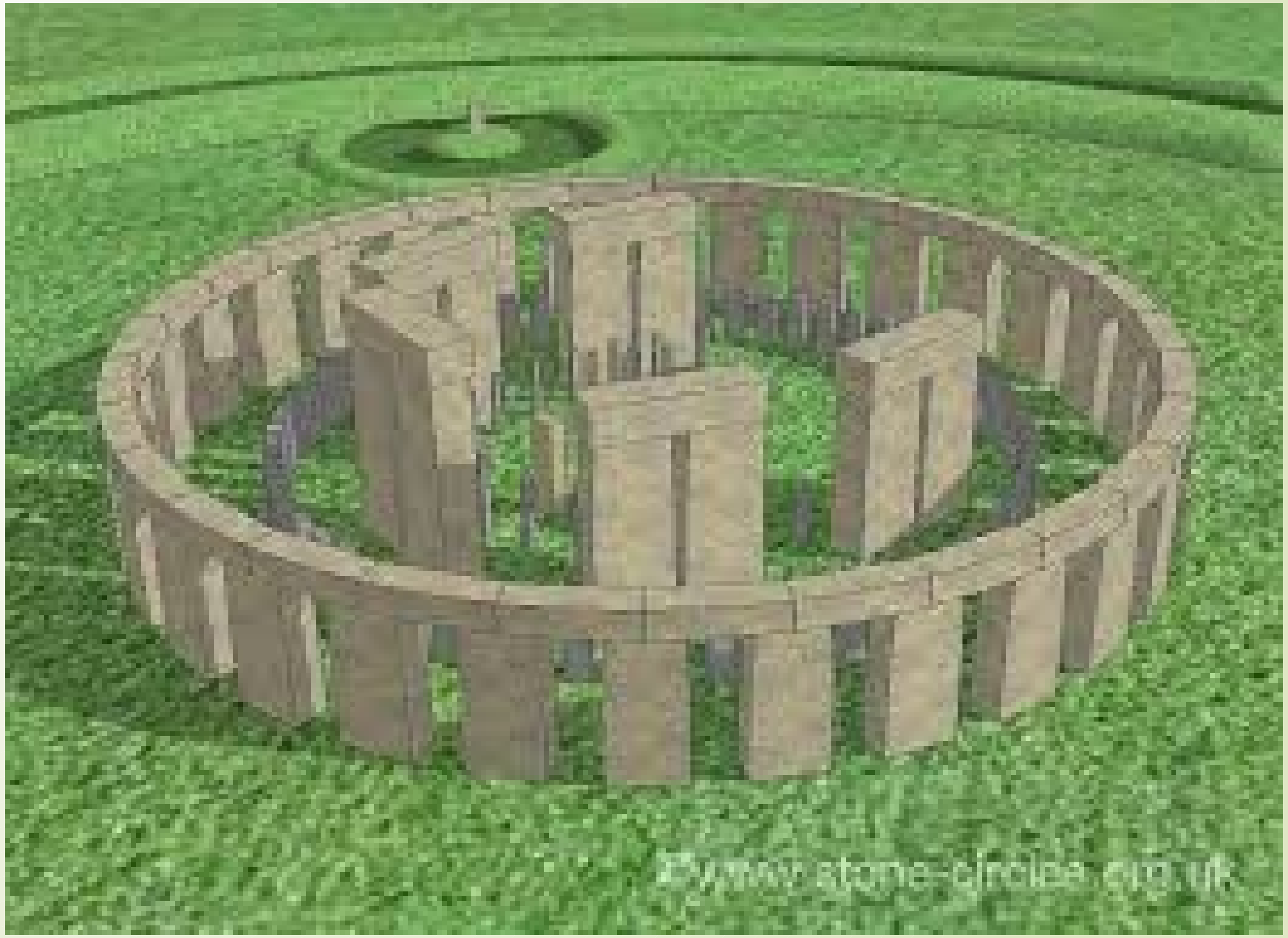

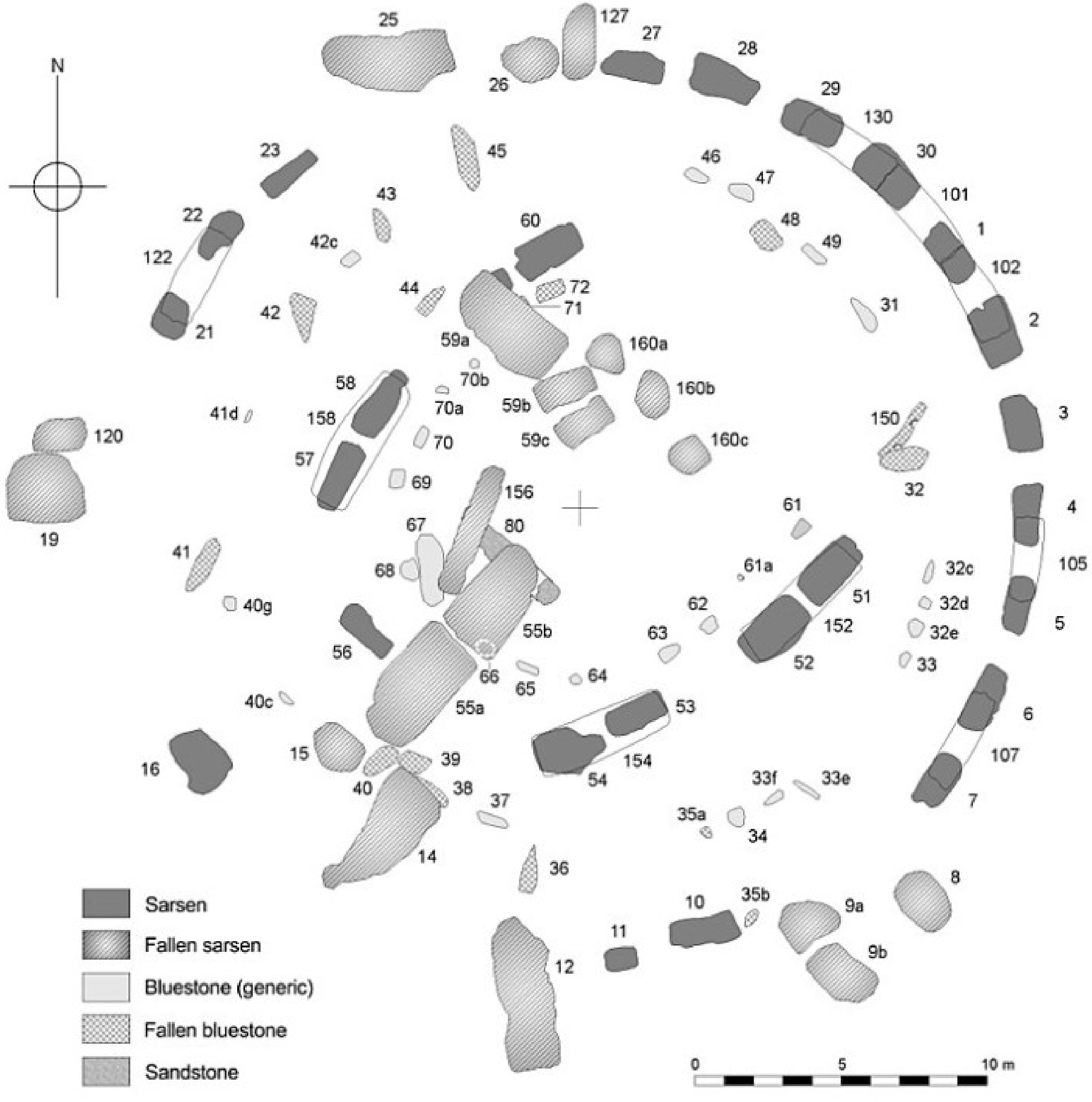
N
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101
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43
42c
42
44
60
72
71
59a
160a
70b
160b
70a
59b
59c
160c
31
150
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3
4
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41d
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40g
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32c
32d
32e
33
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40c
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40
38
37
53
154
54
33f
33e
35a
34
14
36
8
9a
9b
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35b
11
12
Sarsen
Fallen sarsen
Bluestone (generic)
Fallen bluestone
Sandstone
0
5
10 m

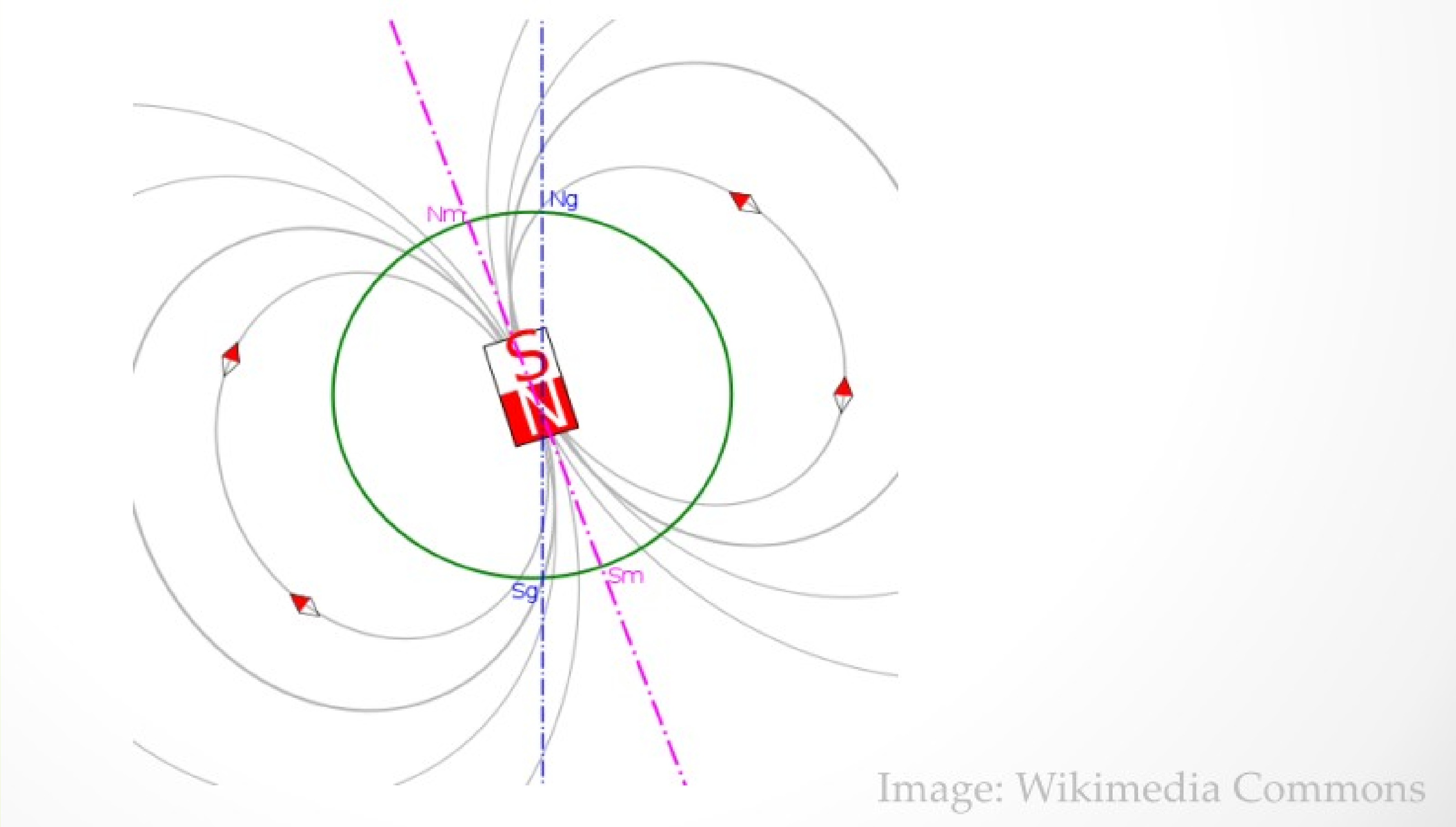
Nm
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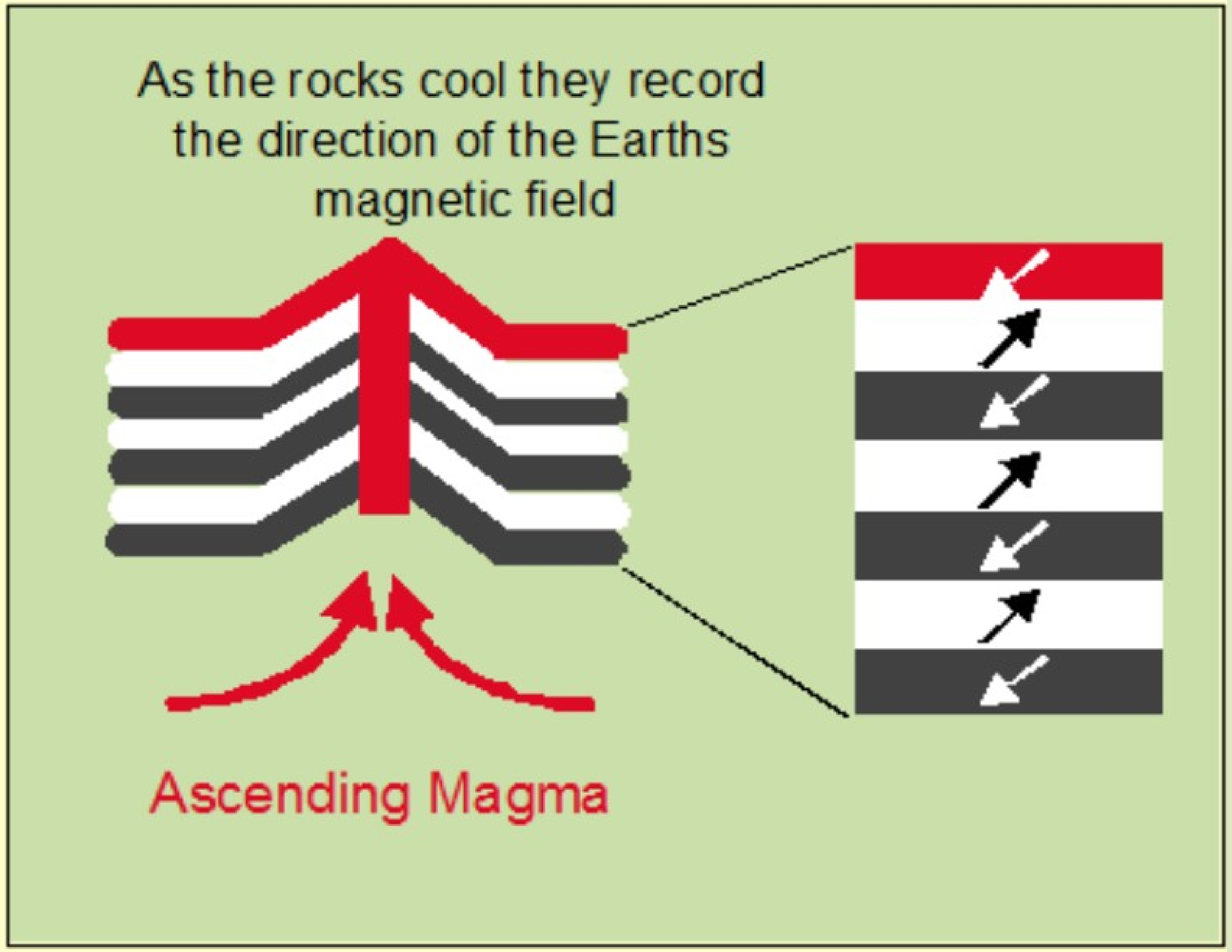
Image: Wikimedia Commons



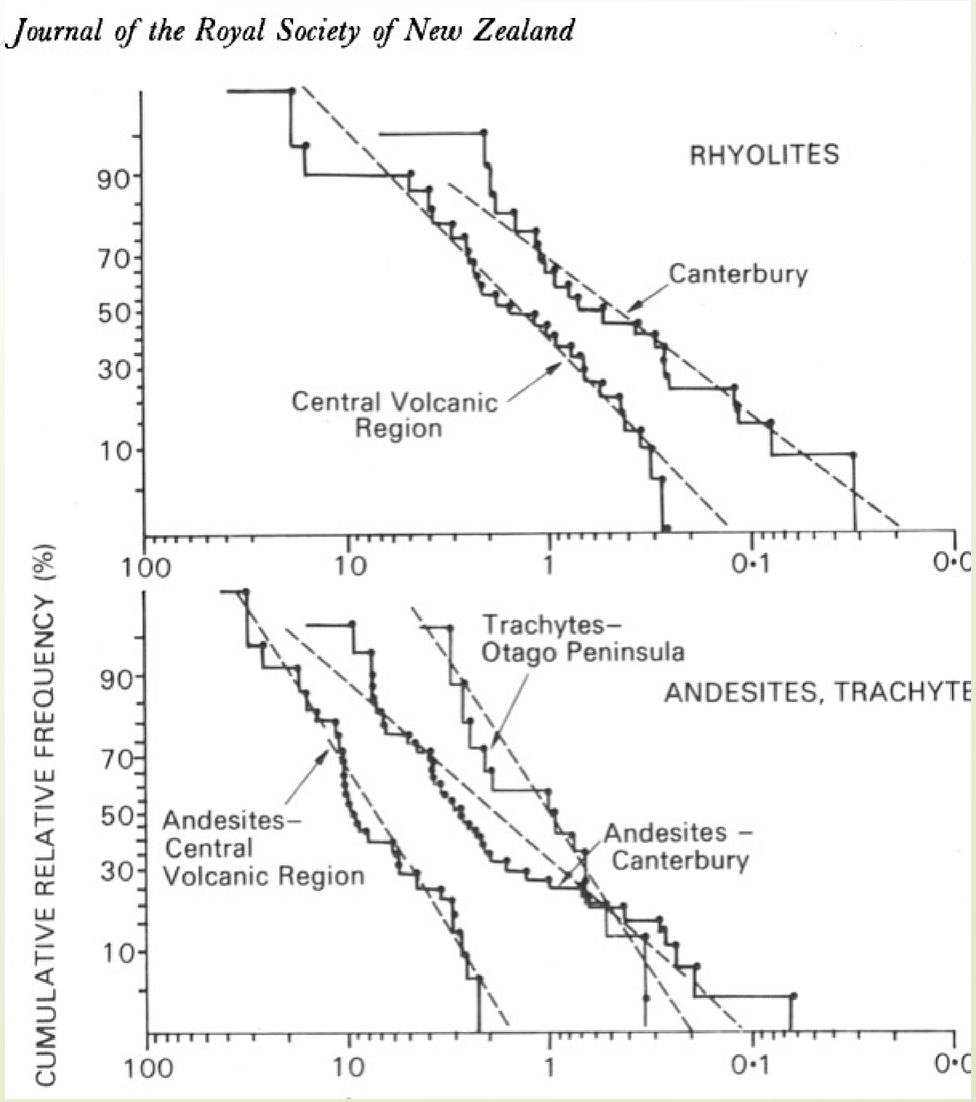
As the rocks cool they record the direction of the Earths magnetic field
Ascending Magma

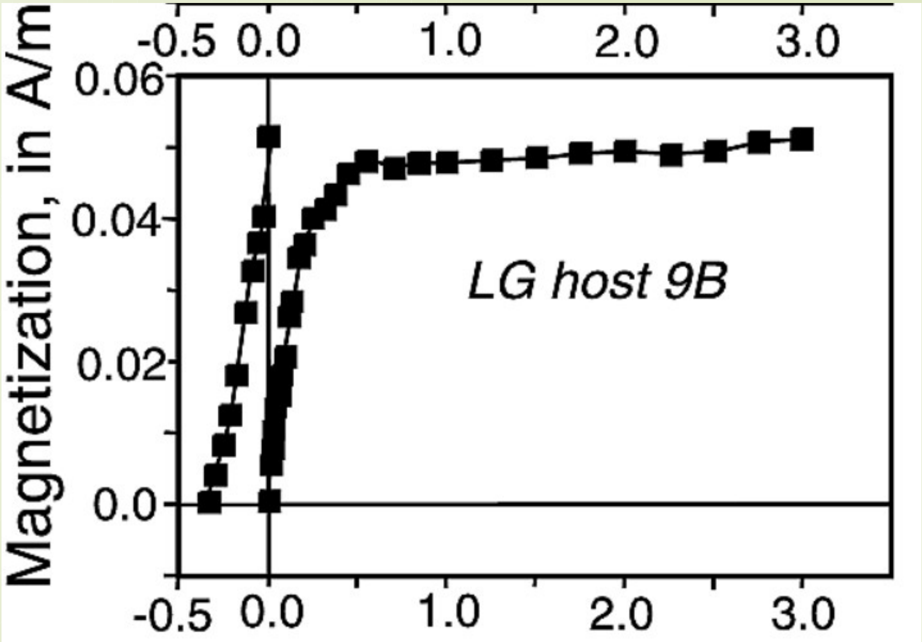
Craig Rhos-y-felin Welsh bluestone

Magnetic Intensity, EI

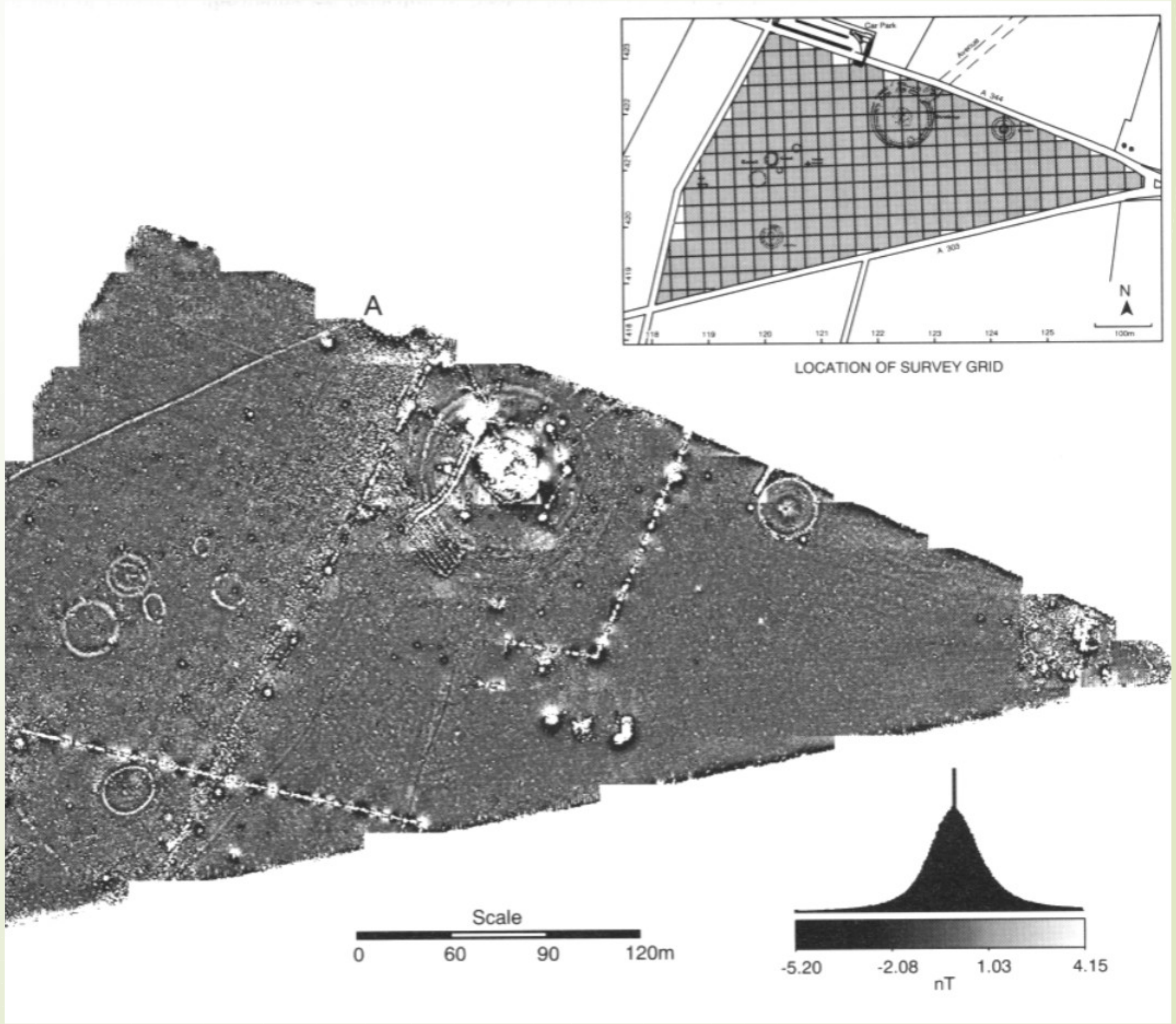
Rhyolite (bluestone)

Sandstone (sarsen)

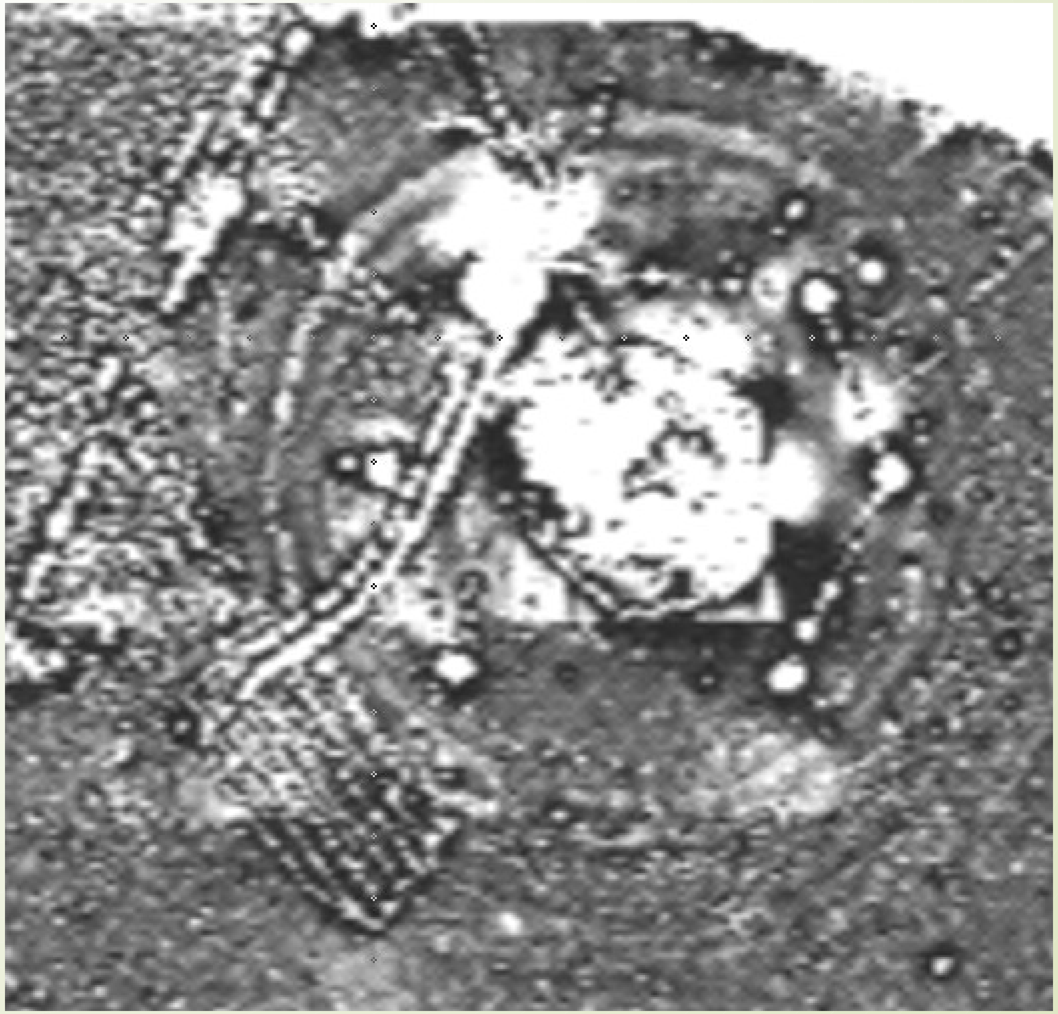


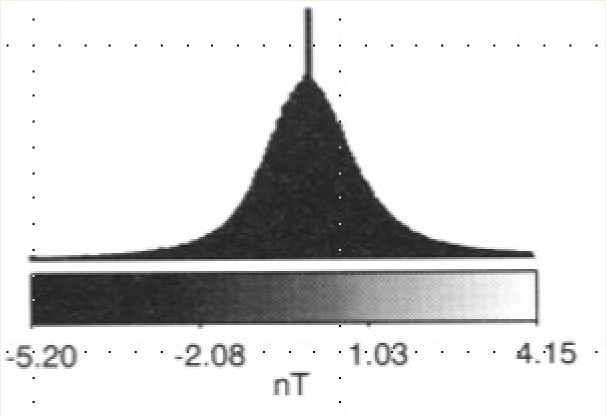


David, A and A. Payne, ‘Geophysical Surveys within the Stonehenge Landscape’, Proceedings of the British Academy, 92, 73-113, 1997



Magnetic anomaly over Stonehenge





ANOMALY EQUATION

Let the xyz coordinates be chosen such that the x-axis points towards geographic north, the y-axis points towards geographic east and the z-axis points vertically downwards. Let the point 0 on the observation plane be taken as the origin of the coordinate system and the observations be taken at grid points laid parallel to the x- and y-axes. Then the equation for the total field magnetic anomaly at any point $P\ (x, y, 0)$ due to a vertical prism whose sides are parallel to the coordinate axes is given by (Kunaratnam, 1981)

$$\Delta T(x, y, 0) = \sum_{k=1}^{2} \sum_{\ell=1}^{2} \sum_{m=1}^{2} S\Big[G_1 \ln (R_{k\ell m} + \alpha_k) + G_2 \ln (R_{k\ell m} + \beta_\ell) + G_3 \ln (R_{k\ell m} + h_m) + G_4 \arctan \frac{\alpha_k h_m}{R_{k\ell m}\beta_\ell} + G_5 \arctan \frac{\beta_\ell h_m}{R_{k\ell m}\alpha_k}\Big], \tag{1}$$

where

$$S = (-1)^{k+\ell+m}, \quad R_{k\ell m} = (\alpha_k^2 + \beta_\ell^2 + h_m^2)^{1/2},$$

$$\alpha_k = a_k - x, \quad k = 1, 2$$

$$\beta_\ell = b_\ell - y, \quad \ell = 1, 2$$

and (a_k, b_ℓ, h_m) represents the coordinates of diagonally opposite corners of the prism. The constants G_1, G_2, G_3, G_4, and G_5 are given by

$$G_1 = EI(Mr + Nq), \qquad G_2 = EI(Lr + Np),$$

$$G_3 = EI(Lq + Mp),$$

$$G_4 = EI(Nr - Mq), \text{ and } G_5 = EI(Nr - Lp),$$

where EI is the intensity of magnetization, L, M, N, are the direction cosines of magnetization, and p, q, r are the direction cosines of the geomagnetic field. If the horizontal sides of the prism are not parallel to the coordinate axes, but are rotated by an angle θ with respect to the geographic north (Figure 1), then we have to choose a new coordinate system (x', y') parallel to the horizontal sides of the prism. The point 0 on the observation plane remains the origin of the new (x', y') as well as old (x, y) coordinate systems. Then the (x, y) coordinates in equation (1) are to be replaced by the new coordinates (x', y') given by

$$x' = x \cos \theta + y \sin \theta$$

and

$$y' = -x \sin \theta + y \cos \theta.$$

If I and D are the inclination and declination of the geomagnetic field, the direction cosines of the field vector are given by

and

$$r = \sin I.$$

If I_0 and D_0 are the inclination and declination of the magnetization vector, then its direction cosines are given by

$$L = \cos I_0 \cos (D_0 - \theta),$$

$$M = \cos I_0 \sin (D_0 - \theta),$$

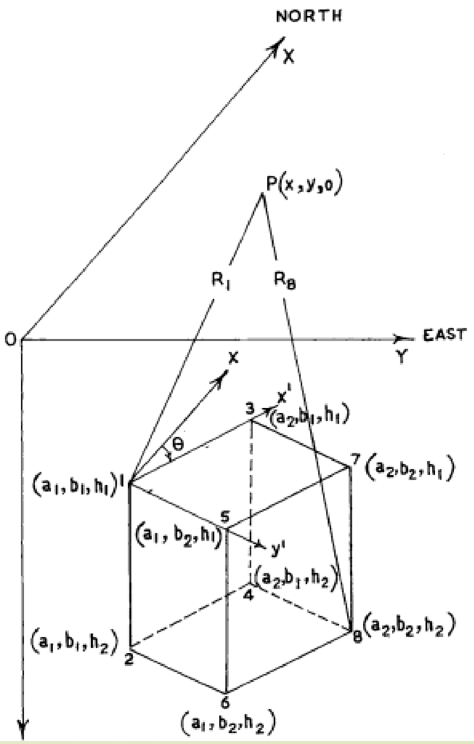
and

$$N = \sin I_0.$$

If the observed anomalies are caused by N_b prisms, the equation for the magnetic anomaly at the field point $(x, y, 0)$ is given by

$$\Delta T(x, y, 0) = \sum_{k=1}^{N_b} \Delta T_k(x, y, 0) + C, \tag{2}$$

where C represents a constant regional. Kunaratnam (1981) has suggested that the logarithmic terms in equation (1) can be simplified as



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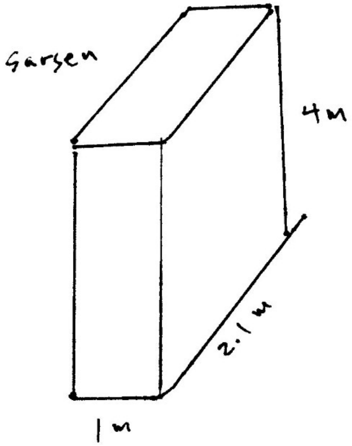
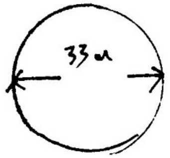




30 stones

51.179 N 1.826 W

IGRF

D .521 W

I 66.14 D

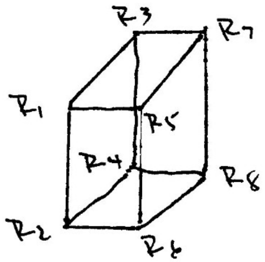
total 48733 nT

EI

rhyolites .1–10 ~~of~~ A/m

sandstone .05

D Rao, N Babu Geophysics vol 56 no 11 1991

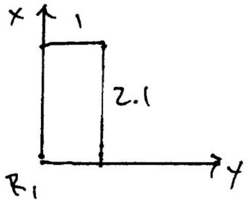


$$\Delta T(x,y,0) = A\left[(G_1\beta + G_2\alpha)\left(\frac{1}{R_1^3} - \frac{1}{R_2^3}\right) + G_3 C_1 \frac{\alpha\beta}{(\alpha^2+\beta^2)} - G_4\frac{(C_1\beta^2 + C_2)}{(\alpha^2+\beta^2)} - G_5\frac{(C_1\alpha^2+C_2)}{(\alpha^2+\beta^2)}\right.$$

$$\alpha = (a_1+a_2)/2 \qquad \beta = (b_1+b_2)/2$$

$$R_1 = (\alpha^2+\beta^2+h_1^2)^{1/2} \qquad R_2 = (\alpha^2+\beta^2+h_2^2)^{1/2}$$

$$C_2 = \left[\frac{h_1}{R_1} - \frac{h_2}{R_2}\right] \qquad C_1 = \left[\frac{h_2}{R_2^3} - \frac{h_1}{R_1^3} - \frac{2C_2}{(\alpha^2+\beta^2)}\right.$$



$a_1 = 0,\ a_2 = 2.1$

$b_1 = 0 \quad b_2 = 1$

$h_1 = -4 \quad h_2 = 0$

$$A = (a_2 - a_1)(b_2 - b_1)$$

$G_1 = EI(Mr+Nq)$ $G_2 = EI(Lr+Np)$ $G_3 = EI(Lq+Mp)$

$G_4 = EI(Nr-Mq)$ $G_5 = EI(Nr-Lp)$

$EI = $ .1–10 rhyolite
$EI = .05\ A/m$ sandstone
~~rhyolite~~

For magnetization along y $p=0,\ q=1,\ r=0$

$G_1 = EI(Nq),\ G_2 = 0,\ G_3 = EI(Lq),\ G_4 = EI(-Mq),\ G_5 = 0$

@ stonehenge

$L = \cos(.521^\circ) \sim 1$

$M = \cos(90-.521) \sim 0$

$N = \cos(90-66.14) = .9145$

$A = (a_2-a_1)(b_2-b_1) = 2.1$

$G_1 = \cancel{.914}\ .9145,\ G_3 = 1,\ G_4 = 0,\ G_5 = 0$

$$\frac{\Delta T(x,y,0)}{EI} = A\left[(G_1\beta)\left(\frac{1}{R_1^3} - \frac{1}{R_2^3}\right) + G_3 C_1 \frac{\alpha\beta}{(\alpha^2+\beta^2)} - \cancel{G_4 \frac{(C_1\beta^2 + C_2)}{(\alpha^2+\beta^2)}}\right]$$

$$\frac{\Delta T(x,y,0)}{EI} = A\left[.9145\beta\left(\frac{1}{R_1^3} - \frac{1}{R_2^3}\right) + C_1 \frac{\alpha\beta}{(\alpha^2+\beta^2)}\right]$$

$$\alpha = (a_1+a_2)/2 - x \qquad \beta = (b_1+b_2)/2 - y$$

want

$$\Delta T(0, 16.5, 0) \qquad x = 0,\ y = 16.5,\ z = 0$$

$$\alpha = 1.05 \qquad \beta = .5 - 16.5 = -16.0$$

$$R_1 = (\alpha^2+\beta^2+h_1^2)^{1/2} = \left((1.05)^2 + (-16)^2 + (-4)^2\right)^{1/2} = 16.525$$

$$R_2 = (\alpha^2+\beta^2+h_2^2)^{1/2} = \left((1.05)^2 + (-16)^2\right)^{1/2} = 16.034$$

$$C_2 = \left[h_1/R_1 - h_2/R_2\right] = -4/16.525 = -0.242$$

$$C_1 = \left[h_2/R_2^3 - h_1/R_1^3 - \frac{2C_2}{(\alpha^2+\beta^2)}\right] = 4/(16.525)^3 + \frac{2(0.242)}{(16.034)^2} = 8.86e{-4} + 18.826e{-4} = 27.686\ {-4}$$

$$\Delta T(x,y,0)/EI = A\left[.9145\beta\left(1/R_1^3 - 1/R_2^3\right) + 6/3\, C_1 \frac{\alpha\beta}{(\alpha^2+\beta^2)}\right]$$

$$= 2.1\left[.9145(-16)\left(\frac{1}{(16.525)^3} - \frac{1}{(16.034)^3}\right) + \frac{(27.686{-4})(1.05)(-16)}{(16.034)^2}\right]$$

$$= 2.1\left[(-14.632)\left(\underset{-.21e-4}{2.22e{-4} - 2.43e{-4}}\right) * -.06534(27.686e{-4})\right]$$

$$= 2.1\left[3.07 - 1.809\right]e^{-4} = 2.648\,e^{-4} = .0002648$$

$\Delta T(0, 16.5, 0) = .0002648 * EI$

$EI_{rhy} \in I[.01 - 10]$

For $EI_{rhy} = 5$, 30 stones

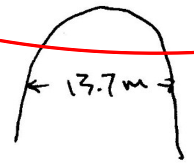
ΔT_{max} rhyolite $\sim 30 * 5 * .0002648 = .039$ nT

$60 * 5 * .0002648 = .078$ nT

ΔT_{max} sandstone $= 60 * .05 * .0002648 = .00079$ nT

Scintrex CS-L Cesium Vapor resolution to .001 nT

Trilithon



10 sarsen 6-7m, 2.1 × 1

$\Delta T(0, 6.85, 0)$ $x = 0$, $y = 6.85$, $z = 0$ $h_1 = -7$, $h_2 = 0$

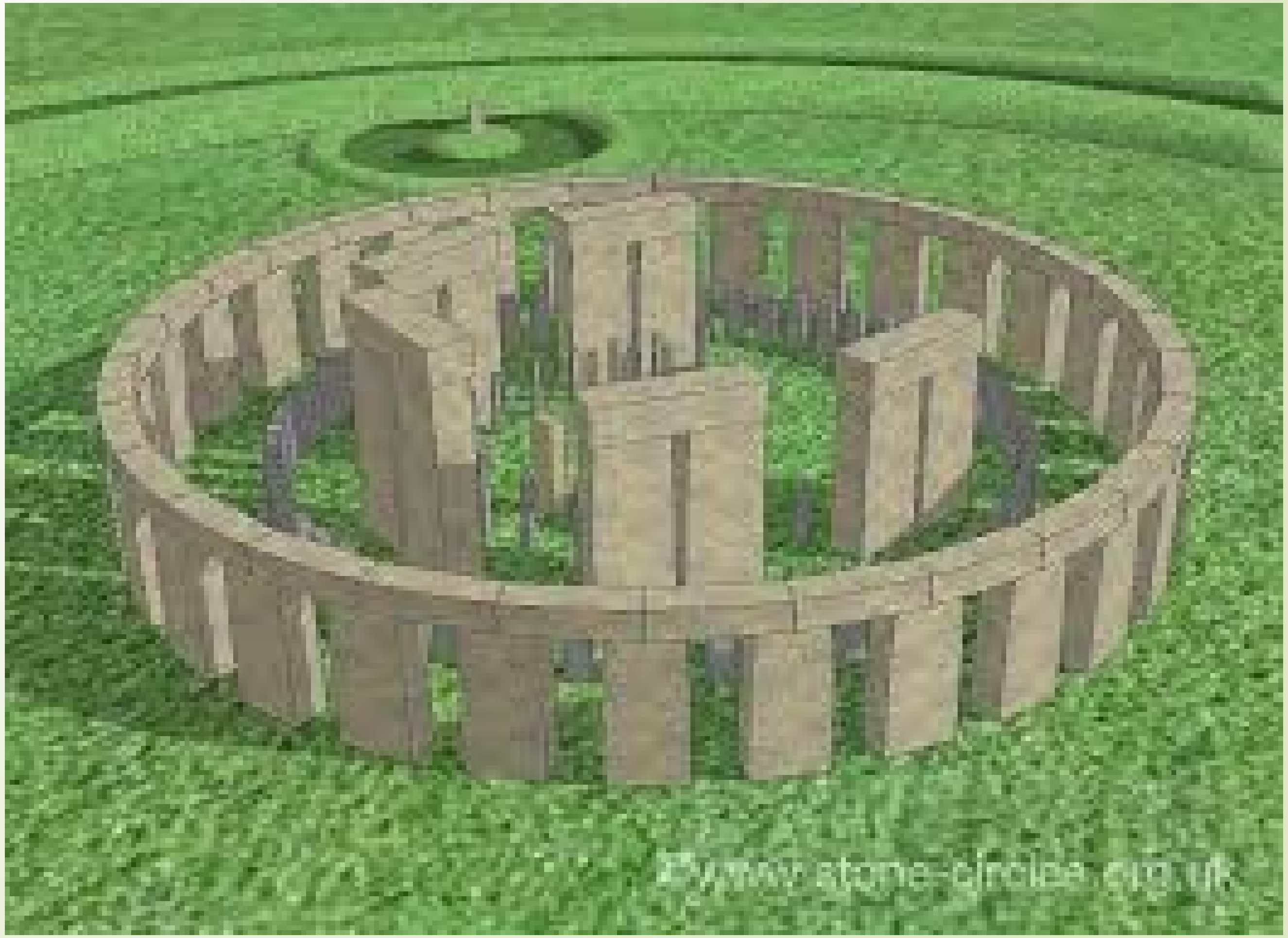
$\alpha = 1.05$ $\beta = .5 - 6.85 = -6.35$

$R_1 = ((1.05)^2 + (-6.35)^2 + (-7)^2)^{1/2} = 9.509$

$R_2 = ((1.05)^2 + (-6.35)^2)^{1/2} = 6.436$

$c_2 = \left[h_1/R_1 - h_2/R_2 \right] = -7/9.509 = -0.736$

$c_1 = \left[7/(9.509)^3 + \frac{2(0.736)}{(6.436)^2} \right] = 1.163e-3 + 35.536e-3 = 36.7e-3$


www.stone-circles.org.uk

$$\Delta T / EI = A\left[.9145\beta\left(\frac{1}{R_1^3} - \frac{1}{R_2^3}\right) + \frac{c_1 \alpha \beta}{(\alpha^2+\beta^2)}\right]$$

$$= 2.1\left[.9145(-6.85)\left(\frac{1}{(9.509)^3} - \frac{1}{(6.436)^3}\right) + \frac{(36.7e{-3})(1.05)(-6.35)}{(6.436)^2}\right]$$

$$= 2.1\left[(-6.264)(1.163e{-3} - 24.14e{-3}) - 5.907e{-3}\right]$$

$$= 2.1\left[143.92 - 5.907\right]e{-3} = .289 \text{ nT}$$

10 stones, $EI \sim 5_e$

$\Delta T_{max} \sim 10(5 * .289) = 14.45 \text{ nT}$

~~rhyton~~ rhyolite

$\Delta T_{max} \sim 10(.05 * .289) = 0.14 \text{ nT}$

sandstone

human threshold

10–20 nT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